# APL - North Pacific Acoustic Laboratory

PI James A. Mercer
Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, WA 98105
phone: (206) 543-1361 fax: (206) 543-6785 email: mercer@apl.washington.edu

CO-PI Rex Andrew
Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, WA 98105
phone: (206) 543-1250 fax: (206) 543-6785 email: rex@apl.washington.edu

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## LONG-TERM GOALS

The ultimate limitations to the performance of long-range sonar are due to ocean sound speed perturbations and the characteristics of the ambient acoustic noise field. Scattering and diffraction resulting from internal waves and other ocean processes limit the temporal and spatial coherence of the received signal, while the ambient noise field is in direct competition with the received signal. Research conducted in the North Pacific Acoustic Laboratory (NPAL) program at the Applied Physics Laboratory (APL-UW) is directed toward a complete understanding of the basic physics of low-frequency, long-range, deep water, broadband acoustic propagation, the effects of ocean variability on signal coherence, and the fundamental limits to signal processing at long-range that are imposed by ocean processes. The long-term goal of NPAL is to optimize advanced signal processing techniques, including matched-field processing and adaptive array processing methods, based upon knowledge about the multi-dimensional character of the propagation and noise fields and their impact on long-range ocean acoustic signal transmissions.

## OBJECTIVES

The scientific objectives of the North Pacific Acoustic Laboratory are:

1. To study the spatial and temporal coherence of long-range, low-frequency resolved rays and modes and the dependence upon ocean processes, transmission distance, and signal frequency.
2. To explore the range and frequency dependence of the higher order statistics of resolved ray and mode arrivals and of the highly scattered finale observed in previous experiments.

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3. To define the characteristics and trends, and determine the relative causes of low-frequency ambient noise on ocean basin scales.
4. To elucidate the roles of internal waves, ocean spice, internal tides, fronts and eddies in causing fluctuations in acoustic receptions.
5. To improve basin-scale ocean sound-speed predictions via assimilation of acoustic travel-time and other data into numerical ocean-dynamic models.
6. To fully analyze our experiment in the Philippine Sea, the results of which will support all of the objectives listed above.

## APPROACH

NPAL employs a combination of experimental measurements, data analysis, simulations, and theoretical development to address the objectives outlined above. These activities are funneled through two primary avenues. The NPAL network, operated and maintained by APL-UW, provides a full-time laboratory for real-time acoustic measurements at a selection of basin-scale locations, the capability to test various transmission signals, and ambient noise (including marine mammals) measurements in the NE Pacific Ocean. The network consists of the legacy SOSUS hydrophone receiver network in the Pacific Ocean, and a data processing and archive center at the Applied Physics Laboratory. Figure 1 illustrates the locations of acoustic hydrophone arrays in the NPAL network.

The second avenue includes highly focused, comparatively short-term experiments.
We have recently completed an experiment in the Philippine Sea called PhilSea10 [1]. The primary institutions were APL-UW, the Scripps Institution of Oceanography (SIO), and the Massachusetts Institute of Technology (MIT). Analysis of environmental data from PhilSea10 has already begun, but the analysis of acoustic data will have to await the recovery of the receiving array in the Spring of 2011. The primary features of PhilSea10 are outlined in Figure 2.

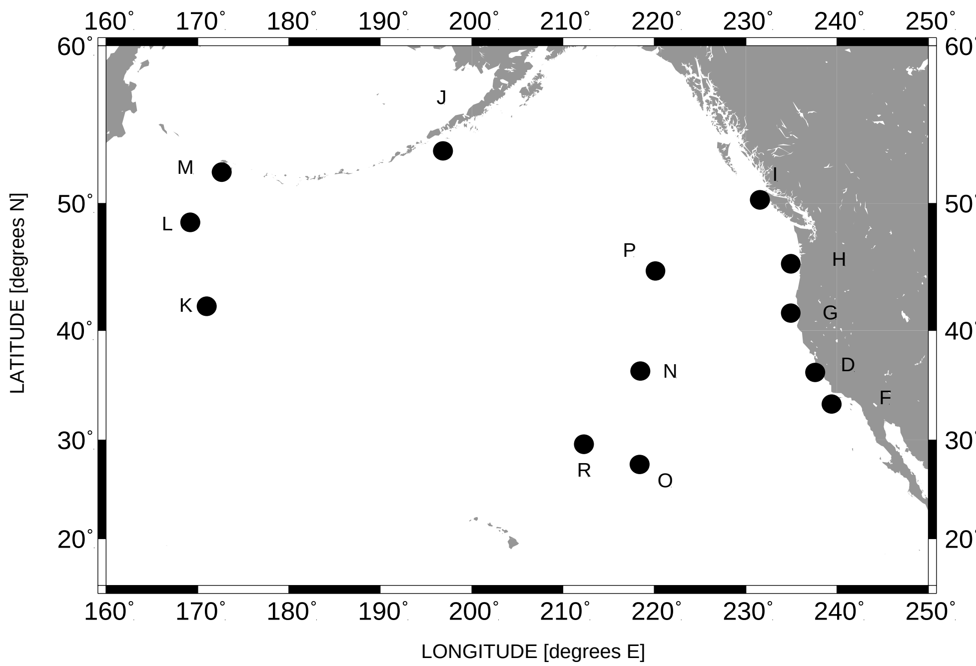



*Figure 1. The NPAL hydrophone array network. The locations of arrays identified by the letters R, D, and F are exact. The other locations are notional. The entire network is controlled and monitored from APL-UW.*

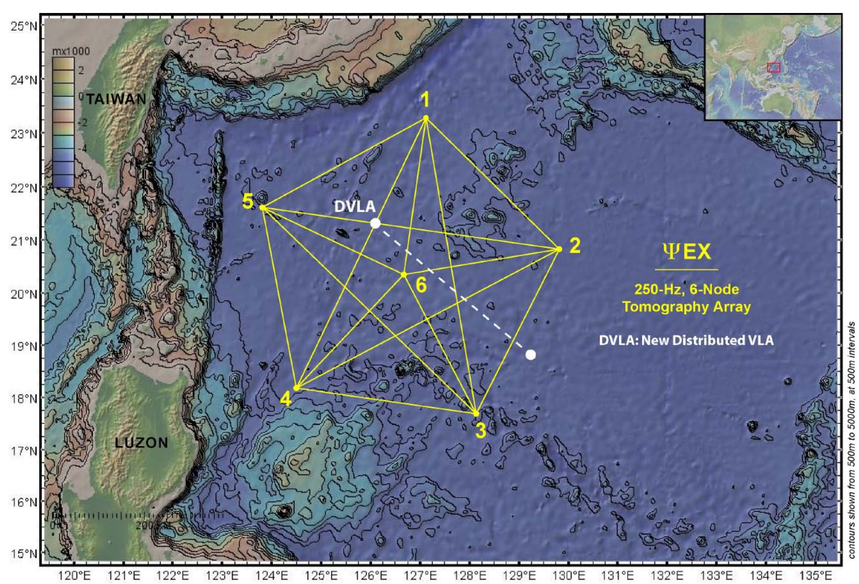



*Figure 2. The 2010 Philippine Sea Experiment; the yellow lines are tomography paths between acoustic transceivers, the DVLA is a full water column hydrophone array, and the dashed white line is a 500 km path for continuous broadband transmissions along which extensive environmental data were collected.*

## WORK COMPLETED

*NPAL Acoustic Network.* A paper titled "Long-Time Trends in Ship Traffic Noise for Four Sites off the North American West Cost" [2] has been submitted for publication in the *Journal of the Acoustical Society of America*. Measurements from four of our network hydrophone arrays located just off the North American west coast permitted extensive comparisons between "contemporary" low frequency (25-50 Hz) traffic noise collected over the last decade to measurements made in the mid-1960s. The exact same locations and underwater equipment were used in the comparison. Although ambient noise in the 25-50 Hz band had increased roughly 10 dB since the 1960s, linear trend lines of the contemporary traffic noise (durations of the past 6 to 12 years) indicate that the current levels are either holding steady or decreasing at three of the four sites.

The NPAL network is autonomous and can be controlled remotely from APL-UW; however, maintenance is sometimes required. Communications from the shore site located at Barbers Point, HI were disrupted when our broad band carrier switched from a 3G to a 4G protocol. A new modem was installed and communications resumed. A failure in the Ling Amplifier at the Kauai site and a broken underground cable were also repaired by APL-UW personnel.

Although ambient noise products are not considered classified, they are processed in a classified facility. A significant effort was put forth this year to re-certify this facility. A request by Mike Brown (RSMAS) for data from Barbers Point was delayed by the re-certification effort.

*LOAPEX Analysis.* APL-UW conducted the Long-range Ocean Acoustic Propagation EXperiment in 2004 between Hawaii and California [3]. The data continue to produce presentations and papers. For example, LOAPEX deployed four Ocean Bottom Seismometers to receive transmissions from our ship-suspended acoustic source. A JASA paper last year [4] described the unexplained receptions. A presentation [5] this year suggests that the deep seafloor arrivals (out to 3200 km range) that are dominant on the geophones but absent on the deep hydrophones may be the result of seafloor interface waves.

Two other papers, based upon LOAPEX acoustic transmissions have been submitted to the *Journal of the Acoustical Society of America.* They are "A modal analysis of the range evolution of broadband wavefields in a deep-ocean acoustic propagation experiment I: low mode numbers" [6], and "A modal analysis of the range evolution of broadband wavefields in a deep-ocean acoustic propagation experiment II: mode processing deficient array measurements" [7].

PhilSea09, PhilSea10, and LOAPEX utilized acoustic sources that were suspended from research vessels to depths as much as 1 km. In order to keep source motion from contaminating estimates of de-coherence due to the ocean, it was necessary to develop source tracking methodology based on several instruments. These included acoustic tracking, a GPS system that incorporated real-time corrections for satellite clock and ephemeris errors, acoustic Doppler profilers, and localized current meters. The results of the analysis of source motion during LOAPEX have been accepted for publication in the *IEEE J. Ocean. Eng.* in a paper titled "Ship-suspended acoustical transmitter position estimation and motion compensation" [8].

*PhilSea10-Experimental Design.* The design of the APL-UW portion of PhilSea10 was relatively simple. The 500-km experimental path is shown as a dashed white line in Figure 2. The principal elements of the experiment were as follows: 1) a 55-hour continuous transmission with the MP

acoustic source from a site 500 km from the DVLA (vertical hydrophone array) and at a depth of 1,000 m, 2) a tow of the CTD Chain along the path toward the DVLA, 3) a tow of the HX acoustic source at a depth of 150 m at ranges between 25 and 43 km from the DVLA, and 4) a series of CTD casts every 10 km from the DVLA back to the original site 500 km away, and 5) a 55-hour continuous transmission with the HX source at a depth of 1000 m. The details of the cruise are contained in the cruise report [1].

*PhilSea10-System Development.* Although the design of PhilSea10 was rather straightforward, several complex systems were developed and deployed. The HX acoustic source was damaged during PhilSea09 and required significant repairs.

Three low frequency acoustic underwater projectors were purchased from Alliant Techsystems in 1993 to support the ATOC (Acoustic Tomography of Ocean Climate) project. These projectors, designated type HX-554, consist of 10 staves configured in a cylindrical array approximately 30 inches in diameter by 45 inches high, not including the tuning transformer and pressurization system. Each stave is a 90-element bender bar transducer. When deployed the cavity inside the cylinder is filled with compressed air to provide the appropriate acoustic compliance-versus-sea pressure at depth. Projectors S/Ns 001 and 003 were installed at select sites off the California coast and north of Kauai, respectively.

The third projector, S/N 002, which was to be a spare, was initially configured for an experiment on FLIP in 1994. This unit was damaged during the FLIP experiment wherein the bars and their stress rod cavities were exposed to sea water. The unit was completely disassembled and the stress rod cavities of the bender bars were flushed with isopropyl alcohol. The projector was then reassembled in the original ATOC configuration and tested but not deployed. It was eventually reconfigured without the ATOC frame and without the outer boot for use as a dipping source. See Figure 3.

While the Kauai installation is still intact and capable of resuming operation the California system has been dismantled though the projector, S/N 001, has not yet been recovered. Recovery of the California projector has been a priority as it would afford a reliable backup to S/N 002. A recovery was scheduled on the *R/V Atlantis* with deep sea submersible *Jason* on board during a transit from San Diego to Astoria, OR in June of 2008. However, due to a combination of inclement weather and engine problems along the way, and the ship's scheduled arrival in Astoria, there was insufficient time to attempt a recovery. Recovery of this projector remains a priority.

Projector S/N 002 was deployed as a dipping source during PhilSea09 at the site of PhilSea10 scheduled for the spring of 2010 in the Philippine Sea. Soon after the unit was deployed it exhibited a short that could not be corrected on site. As it was being disassembled at the Laboratory it became evident that multiple and catastrophic failures had occurred. A total of four bender bars had at least one broken stress rod (Figure 4). Bender bar S/N 016 (Figure 5) and one other bar had shattered elements.


*Figure 3.  HX-554 projector configured as a dipping source.*

*Figure 4.  Bender bar with broken stress rod.*

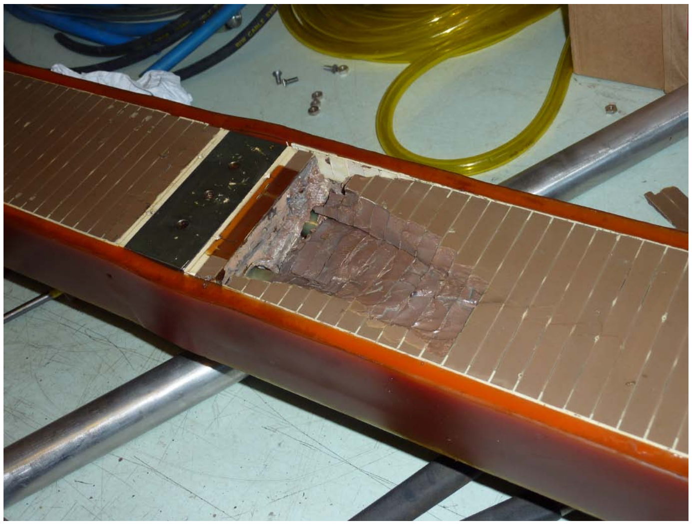


***Figure 5. Bender bar S/N 016 showing shattered elements.***

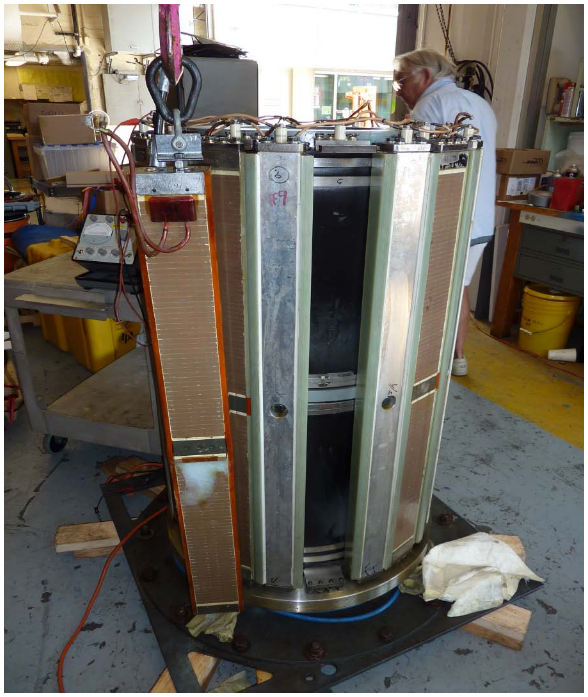


***Figure 6. Installing bender bar S/N 016 as an inactive stave.***

As none of these bars could be repaired or replaced it was decided to reassemble the projector using only five active bars spaced for symmetry. The remaining five bars were installed in order to provide structural integrity and a complete enclosure for proper pressurization but they were not electrically connected. Figure 6 shows a damaged bar ready to be put in place between two active bars. The figure also shows the heavy aluminum spacers that are installed between the bars. The power level for the PhilSea10 experiment was reduced slightly as a safety factor and the projector performed flawlessly during its two deployments.

The other acoustic source, known as the Multi-port or MP source, was also damaged during PhilSea09. A pressure compensation hose to the tuning autotransformer became disconnected and allowed sea water to damage the transformer. Its primary function is to boost the voltage applied to the transducer. Its secondary function is to adjust the power factor of the transducer as seen by the power amplifier. The first version of the system autotransformer was fabricated in 2008 by Coiltron, Inc (Tigard, OR). The damaged unit was returned to Coiltron with instructions to salvage the core and build a replacement autotransformer. The new autotransformer has two tap settings, providing inductances of 220 mH and 300 mH, respectively: both tap settings up-convert the amplifier drive voltage by a factor of 2. The history of system development from 2005 up to this reporting period has been documented in an APL technical report [9].

The two acoustic sources were suspended from the research vessel *REVELLE* on a mechanical/ electrical/optical cable. The introduction of optical fibers for PhilSea09 allowed reliable monitoring of the acoustic sources in real time, improved acoustic navigation of the sources, more reliable transponder surveys, and easier deployments of the hardware over the stern of the research vessel. One addition for PhilSea10 involved an optical control line for the gas pressurization system on the HX source. Once this source reaches operational depth, a valve is activated to release air from high pressure cylinders mounted below the source into the interior of the source to improve compliance for the acoustic elements. This valve had been activated by an acoustic command from the ship. This acoustic link was difficult to achieve and confirmation of activation was unreliable. The optical control line solved this problem and was a significant time saver in PhilSea10.

In order to improve the conduct of navigating the sources acoustically and assist the surveying of bottom transducers used in the navigation, a software utility was developed to display relevant data. The snapshot shown in Figure 7 captures an actual display of acoustic survey data taken during PhilSea10. During planned transmissions from the sources, while acoustic navigation was taking place, the display not only provided control of the acoustic interrogator and monitoring of the receptions, it also displayed a readout of the source depth (pressure) and the status of battery power supplies for the subsea electronics. This innovation proved to be a great asset, particularly for maintaining reliable acoustic survey and navigation data. The graphical display easily identifies outliers and allows the channel gains and delays to be quickly reset if necessary to maintain good acoustic data.

An analysis of the acoustic navigation data has been completed and the results are reported in "NPAL 2010 Cruise Tracking Report" [10]. The analysis indicates typical horizontal velocities of the suspended source of 0.02 m/s or less, suggesting that source Doppler should not be a significant issue for Doppler-insensitive statistics.

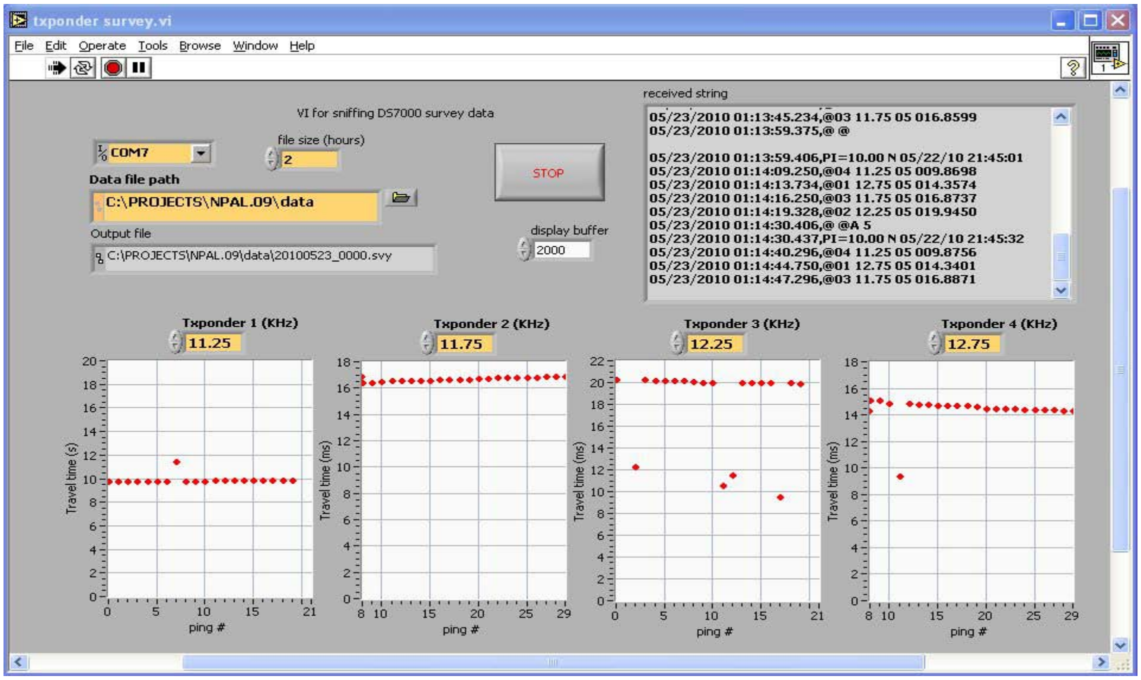



***Figure 7. Snapshot of acoustic survey screen.***

The hardware and software discussed above were tested in Lake Washington in January 2010. Although actual source transmissions were not allowed, it was possible to determine that all supporting systems were operating normally.

*PhilSea10-Towed CTD Chain.* The Towed CTD Chain (TCTD) is an 800 m long cable instrumented with 88 sensor fins (originally to be 100 fins but 12 from previous field use were broken and unavailable at the time of our cable assembly); see Fig. 8 for a notional diagram. Each fin has onboard sensors to measure temperature, conductivity, and pressure like a traditional CTD instrument. A traditional CTD is generally cast at one geographic point location while the ship is stopped, yielding very high depth resolution CTD measurements at that single point location. In contrast, the TCTD is meant to yield a relatively high resolution (on the order of 5m both vertically and horizontally), 2D vertical slice of the ocean, with CTD measurements down to 500-600m depth for as far as one wishes to tow the cable. Unlike other towed instruments such as the SeaSoar [11], the TCTD simultaneously takes measurements over the entire depth range every few seconds, resulting in much higher spatial and temporal resolution.

However, while this system's concept is very attractive, and a few much smaller versions of it have been used successfully in the past, including Shallow Water 2006 (SW06) [12,13], the present large-scale version of it has a number of technical problems, both mechanical and electrical. Many mechanical problems were revealed during PhilSea09 and those which could be addressed by APL-UW were resolved, but many problems remained and they greatly constrained the measurements in PhilSea10 and their usefulness. The fundamental problem is a lack of sensor fin response – in SW06 typically 90% of the sensors responded, compared to 20-60% (typically 30%) in the PhilSea10 (Table 1).

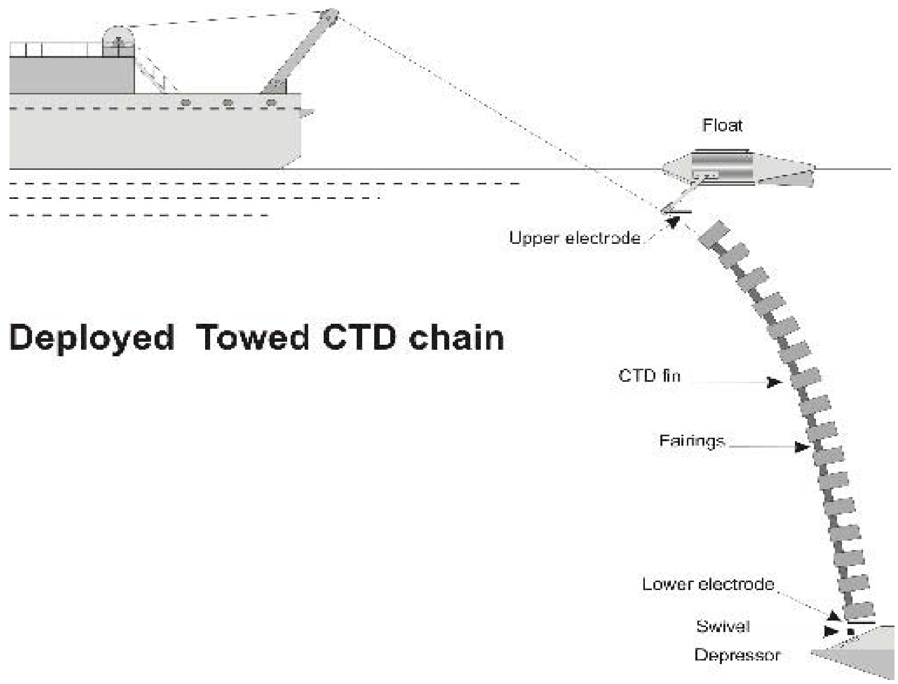



***Figure 8. Notional diagram of towed CTD chain (TCTD), reproduced from website of ASD Sensortechnik.***

***Table 1. Percentages of responding TCTD sensor fins in various NPAL tests/situations.***

| **Date/situation** | **Approx max % of responding sensors** |
|---|---|
| PhilSea09 beginning of tow1 | 60% |
| Majority of PhilSea09 | 25% |
| Testing DRY on NOAA runway, Nov-Dec 2009 | 60% |
| Test in Puget Sound, Jan 2010 | 40% |
| PhilSea10 test DRY on reel before first deployment | 40% |
| PhilSea10 beginning of tow1 | 55% |
| PhilSea10 beginning of tow2 | 30% |
| Majority of PhilSea10 (in both tows) | 25-30% |

After the instrument's failure of its acceptance test in the PhilSea09 cruise, the months until the PhilSea10 cruise were spent in a series of upgrades and associated tests of the TCTD system. Electronic upgrades in conjunction with the manufacturers, ADM Elektronik, included: a replacement deck unit provided by ADM which allowed for increased power (via increased current) to be sent down the sea cable, frequency changes in the cable signal (earlier work on the previous deck unit had similarly allowed such frequency changes), new USB interface circuitry aiming to interface with a Windows rather than DOS computer, and new acquisition software. In Nov-Dec 2009, field tests were

conducted with this new electronic hardware and software, with the sea cable laid out dry on a NOAA runway to avoid the strong inductive load seen in previous tests on looped sea cable. Meanwhile APL was developing a new armored towline, deployment block, and stronger upper termination to address the mechanical problems in which stresses and impacts on the upper termination had continually disconnected and also damaged the sea cable in PhilSea09. In Jan 2010 an end-to-end electrical test of all the new apparatus (minus the powered reel) was conducted on APL's *R/V Robertson* in Puget Sound. A meticulous meter-by-meter check of cable-jacket integrity was done via electrical insulation tester as the cable was gradually deployed into the salt water, and remaining unseen cable faults from 2009 cruise were repaired. The hardware and software updates described above were tried again on Puget Sound as well. Table 1 lists system performance via approximate percentage of responding sensor fins in the various tests and cruises. Best performance dry or in water still has only about 60% of sensor fins responding, and in situ this number rapidly dwindle with seawater gradually entering the cable (which appears unavoidable when using the cable currently specified by the TCTD manufacturer). Signal timing and signal degradation troubles have been documented by APL as well though, and overall it is still not understood by APL or the manufacturer what causes the remaining 40% of fins to not respond even under the most ideal conditions (e.g. dry and laid out straight), or how the system can be made more electrically robust to small micro-leaks in the sea cable.

## NEW RESULTS

It is unfortunate that acoustic data from the DVLA will not be available until Summer of 2011, but there are still some interesting results from PhilSea10 that can be presented now. As mentioned above, the APL cruise included an extensive CTD survey with conventional CTDs. The survey included 51 CTD casts spaced every 10 km from a location near the DVLA to the site where the 55-hour acoustic transmissions took place. Most of the casts were to 1500 m, but every fifth cast was to full ocean depth. Figure 9 presents a map of the computed sound speed along this 500 km track with the mean sound speed removed. This figure clearly indicates exceptionally strong range dependence in the sound speed structure. Apparently a front between two eddy regions lies across this path. Additional strong variability exists between the ranges of 200 and 500 km.

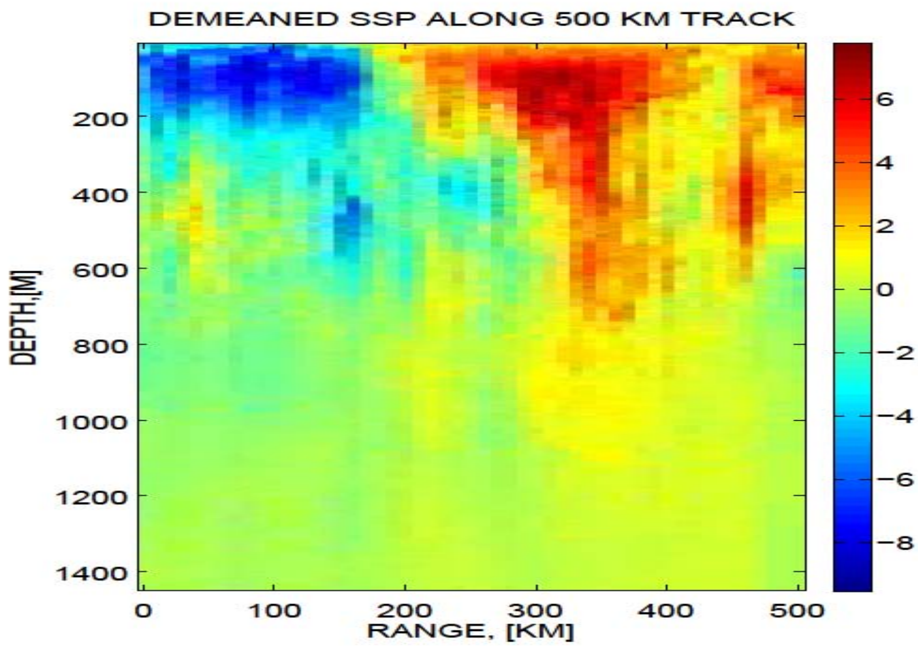



***Figure 9. Demeaned sound speed computed from 51 CTD casts along a 500 km path in PhilSea10.***

As described above, the performance of the Towed CTD Chain was disappointing, however some data were in fact obtained in the PhilSea10 experiment, and analysis regarding variations via internal waves and spice has commenced on this data. A few preliminary plots of the data are shown below. Two tows of the TCTD were performed and roughly overlapped each other, separated by eight days during which a sequence of CTD casts were also made along the same track (and beyond). The tow region was in approximately the southeast 100km of the path between the DVLA and SS500 (see Fig. 10).

Measurements at sampling periods of 3-5s were obtained during these two tows, with one to three dozen sensors distributed over 700m depth. The first tow was 93km for about 39 hours and the second tow was 124km for about 30 hours. The pressure data was augmented by one or two Seabird CTDs mounted on the TCTD sea cable (one at cable bottom in tow #1, and additionally one mid-cable in tow #2). Preliminary processing showed significant sound-speed structure in the data, as for example in Fig. 11 which shows interpolated anomalies from the background mean sound speed in tow #2.

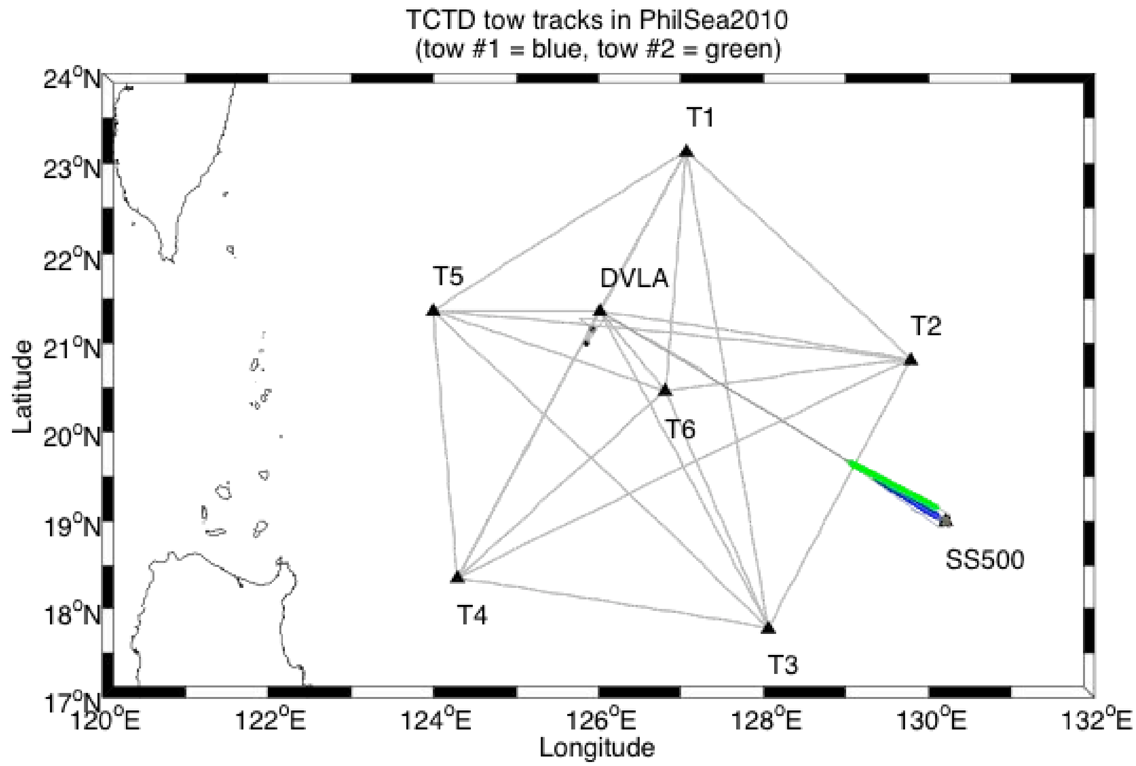



***Figure 10. Path locations of the two TCTD tows during the PhilSea10 experiment.***

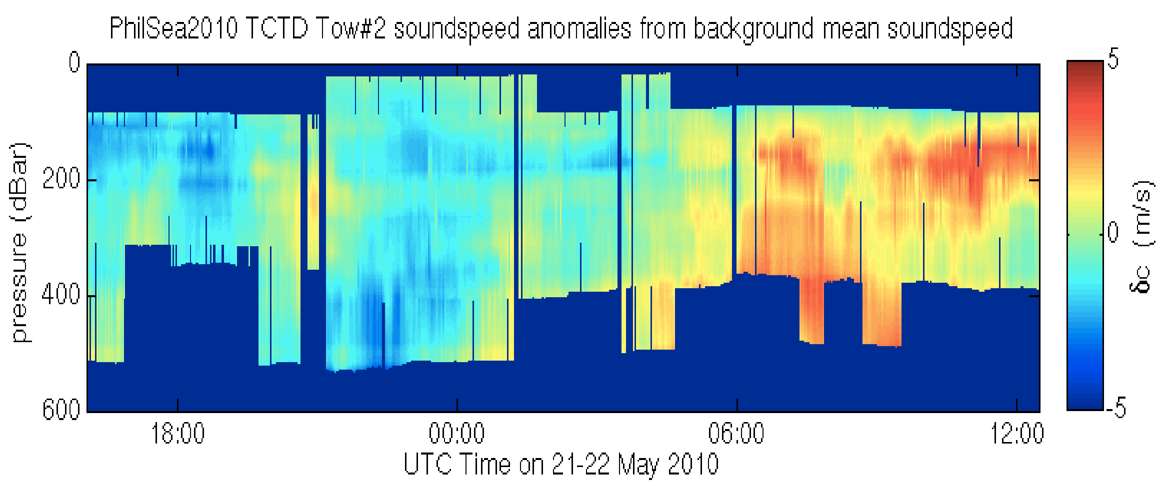
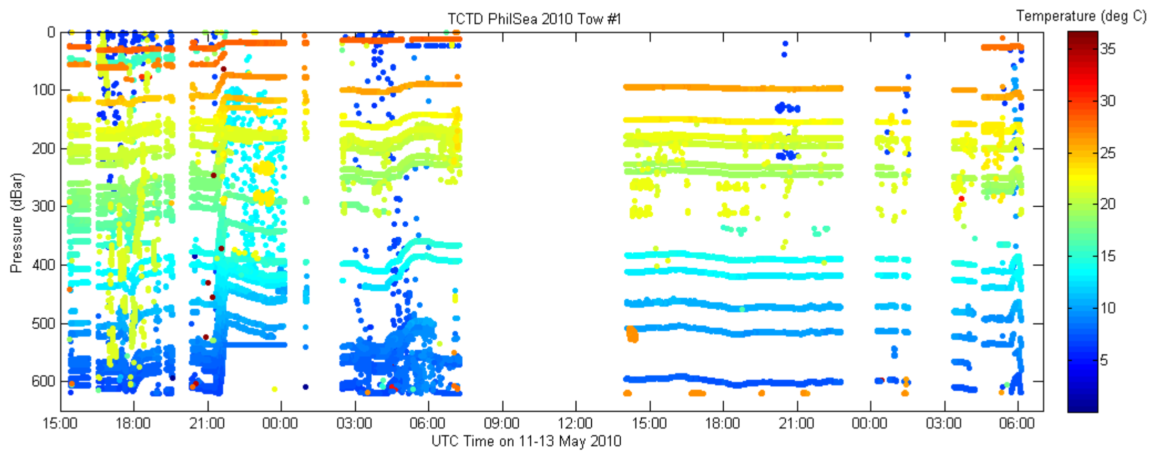
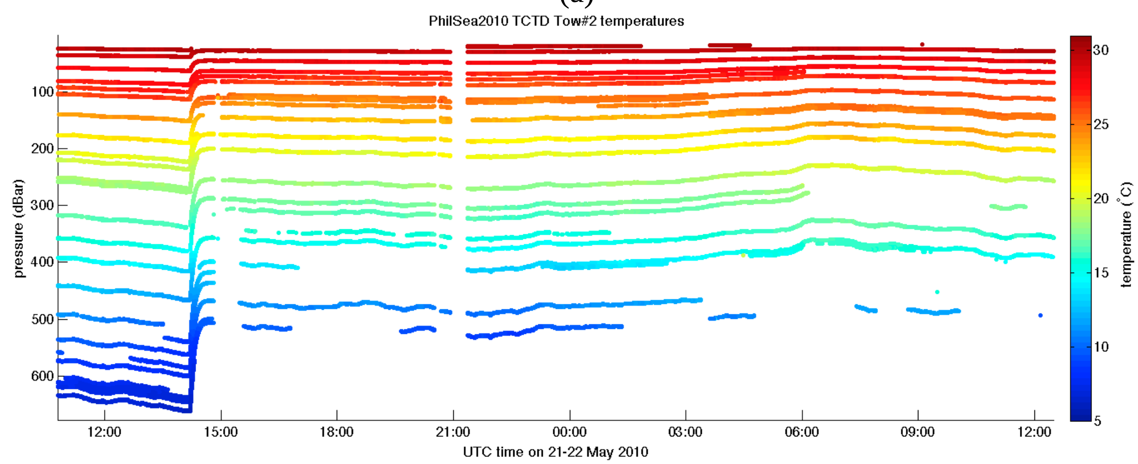



***Figure 11. Preliminary plot of interpolated anomalies from background mean sound speed in PhilSea10 TCTD tow #2.***

Analysis has only just begun on the PhilSea10 data, but the data coverage for each of the tows can be expressed as in Fig. 12. That figure shows temperature data in colors for each sensor in its path through depth and time. Temperature is shown because it was the most reliable sensor. Tow #1 has not yet been rigorously cleaned due to complications from numerous non-flagged diagnostic power-data samples that were interspersed with the environmental data bytes (these were turned off in tow #2 after seeing the effort in separating them).




(a)




(b)

***Figure 12. Data coverage for PhilSea10 TCTD tow #1 (a) and tow #2 (b). Temperature data is shown because it was the most reliable sensor. Tow #1 has not yet been rigorously cleaned due to complications from numerous non-flagged diagnostic power-data samples that were interspersed with the environmental data bytes.***

Another new result from PhilSea10 was the use of dual, or two-color, acoustic transmissions from the MP source. Since the MP transducer has two resonance frequencies, and since the device is more-or-less linear, one should be able to construct a drive signal containing the superposition of a signal with a carrier at the lower resonance and a second signal with a carrier at the upper resonance.

In order to build a composite “dual frequency" drive signal that would be compatible with the transmitter software, the two signals were required to be of equal length over a single signal period. This was simply accomplished by setting one carrier at 200 Hz and the other at 300 Hz, and adjusting the signal Q's to have a 2:3 ratio. This latter adjustment directly defines the number of carrier periods per chip in the respective m-sequences.

Such “two-frequency" signals have been used before in long-range ocean acoustics in the AST experiment, which used carriers around 28 and 84 Hz. Two-frequency signals have also been used in WPRM measurements of the atmosphere, where they are sometimes called “two-color" or even “bi-chromatic" signals.

The two m-sequences in the drive signal are simply summed, so the laws for the two signals were chosen to be different. This allows the time fronts of the two signals to be measured independently. One advantage of this scheme, as shown below, is that a mediocre response for one of the m-sequences need not interfere with a good response for the other m-sequence. One gets two signals for the price of one!

This “bi-chromatic" signal was designed with the parameters shown in Table 2. Adopting the “two-color” nomenclature from atmospheric WPRM, the two components are labeled “red” and “violet”. There are 175.95 pulses per hour for either component, and no pre-equalization was used on the basic signal. A custom C program `makedualmseq` was written to generate the signal file. A section of the raw waveform is shown in Fig. 13.

***Table 2**. Parameters of the two component m-sequences in the experimental “bi-chromatic” MP200 signal.*

| Parameter | | Red signal | | Violet signal |
|---|---|---|---|---|
| Carrier | | 200 Hz | | 300 Hz |
| Law | | 2033 | | 3471 |
| Sequence length | | 1023 | | 1023 |
| cycles/digit | | 4 | | 6 |
| Digit length | | 20.00 ms | | 20.00 ms |
| Bandwidth | | 50.00 Hz | | 50.00 Hz |
| Sequence period | | 20.46 s | | 20.46 s |

Autospectra for the drive signal and the monitor channel signal are shown in Fig. 14. The sharp response of the MP transducer near 210 Hz clearly provides unfavorable “sharpening” of the “red” component spectrum.

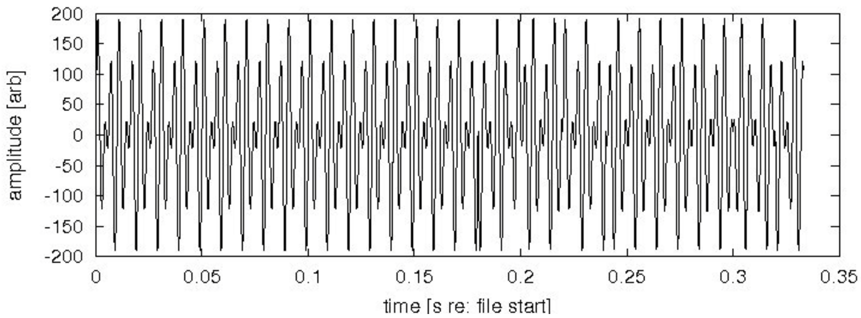



***Figure 13. Dual m-sequence signal raw waveform.***

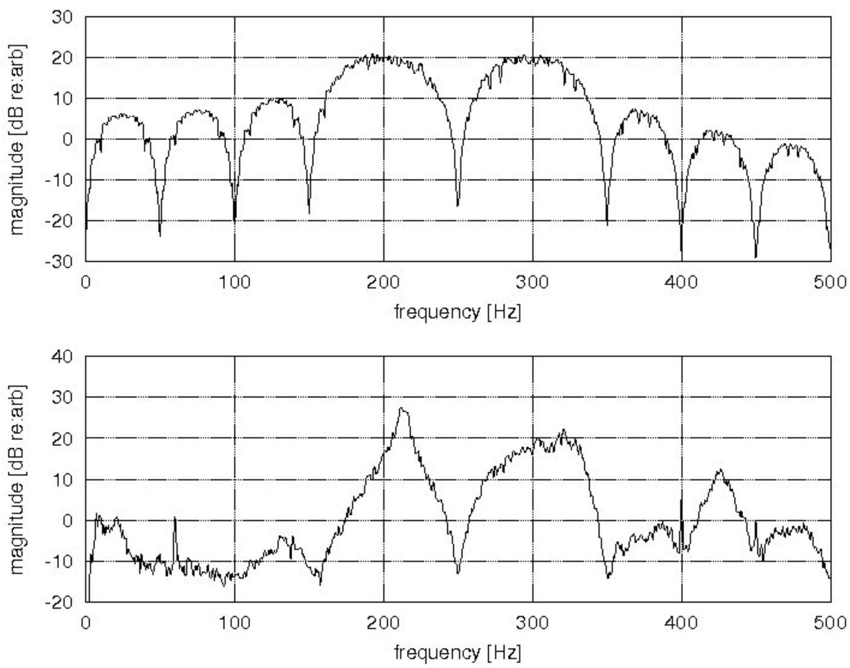



***Fig. 14 Dual m-sequence autospectra. Top panel: drive signal, estimated from the drive waveform file. Bottom panel: monitor hydrophone signal, estimated from 30s of data.***

Pulse compressed waveforms for both the drive and monitor hydrophone channels are shown in Fig. 15. The pulse response of the violet component is comparable to that in the drive signal --- this can be inferred from Fig. 14 because the spectral shape around 300 Hz in the radiated spectrum has a shape comparable to that in the drive signal. The pulse response of the red component is considerably broadened compared to that in the drive signal, and this can also be inferred from Fig. 14 because the spectral shape around 200 Hz in the radiated spectrum is much narrower than that in the drive signal.

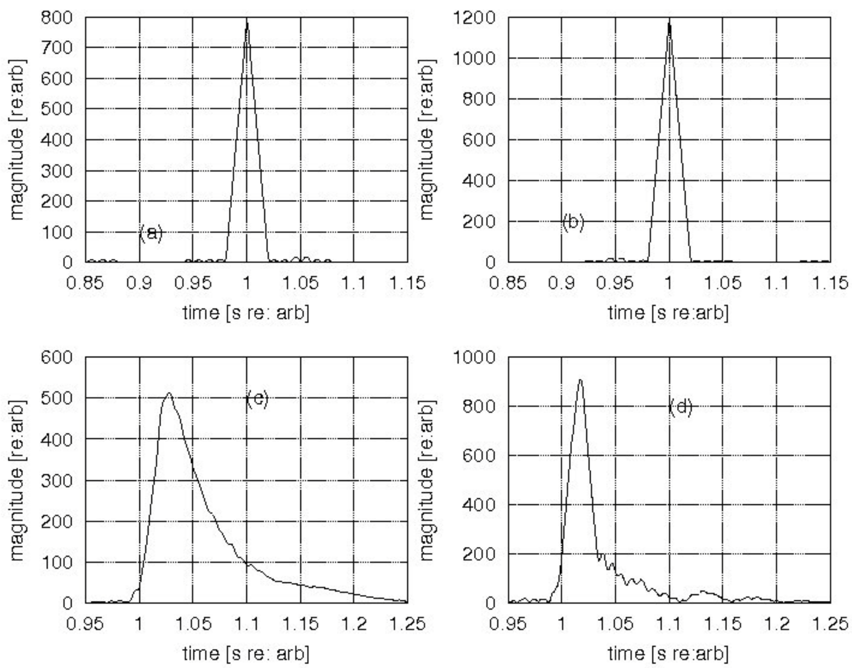



***Fig. 15. Dual m-sequence pulses after pulse compression. Panel (a): red component, drive signal. Panel (b): violet component, drive signal. Panel(c): red component, radiated signal. Panel (d): violet component, radiated signal.***

These results suggest that post-processing for the MP source signal may be required to equalize the spectral shaping induced by the transducer to improve the timing resolution and/or decrease the trailing side-lobe energy in the “red" component, and perhaps in the “violet" component as well. Future work will investigate whether or not post-equalization is worthwhile.

**GRADUATE STUDENT GRANT (N00014-08-1-0200)**

Mr. White has made excellent progress toward his Ph. D. degree and is making significant contributions to the NPAL program. Mr. White collaborated in an analysis of the PhilSea09 CTD cast data taken during both the Scripps deployment and recovery cruises, and the APL-UW cruise. This included determination of parameters describing the spatially and temporally-averaged buoyancy frequency and sound-speed. In addition, the perturbations were filtered and contributions from spice and internal waves were separated. The conclusion for PhilSea09 was that there was less evidence of spice in the Philippine Sea than was observed in the north central Pacific Ocean, which was sampled during LOAPEX [1]. Mr. White also applied fall-rate corrections to the XBT data. This work was presented at the 2009 NPAL Workshop [14].

Mr. White wrote an internal-wave-based sound speed perturbation generator and integrated it into his PE code in order to be able to do Monte Carlo PE simulations. He modeled the Philippine Sea environment using the buoyancy frequency and sound speed profiles mentioned above, adding Garrett-Munk internal wave perturbations. He then completed Monte Carlo PE simulations of broadband

acoustic propagation of a 75-Hz signal through the modeled Philippine Sea environment. He presented this work at the October 2009 ASA Conference [15]. Some relevant predictions was the scintillation index for 75 Hz signals along various paths. Mr. White also performed convergence tests with the PE code in order to determine the appropriate range step and number of internal wave modes to be included in GM oceans for 284 Hz center frequency acoustic simulations.

We required an estimate of amplitude fluctuations due to changes of the receiver position in the acoustic field. The ray method provides an accurate prediction of deterministic amplitude at positions sufficiently removed from caustics. Mr. White computed eigenrays to all tracked upper array hydrophone positions relative to each of the two APL-UW source deployment ranges during the month-long deployment of the DVLA. He then made an estimate of the scintillation index due to changes in receiver position for the two source deployment ranges.

The transfer function of the MP acoustic projector consisted of two sharp peaks at frequencies of 210 and 320 Hz. Since the ideal transfer function would be “flat” across these two frequencies, the M-sequence waveform was “pre-equalized” [9]. The pre-equalization filter was not expected to be optimal for full-power at-sea operation, and substantial ringing in the pulse-compressed signal recorded on both the monitor hydrophone and the 45 km distant Scripps DVLA was observed. Dr. Rex Andrew (APL-UW) therefore designed a filter to “clean up” the recorded signal prior to pulse-compression. Mr. White applied this filter to acoustic receptions made on the Scripps DVLA. When Mr. White plotted the reception on all hydrophones of a single acoustic pulse, we noticed that the signal seemed to arrive at different times for each hydrophone. This caused the time front to appear ragged. Apparently the sample rate of each hydrophone, which is set by its internal oscillator, can be slightly different than its nominal value of 1953.125 Hz [16]. He corrected this error in a rough fashion by skipping to the sample nearest the actual transmission time at the start of each transmission. For the long-duration transmissions, this method results in an error of less than one sample over the duration of the transmission. For the worst-case clock-rate error, the effect on the amplitude estimate was negligible. The results of this clock correction are shown in Figure 16.

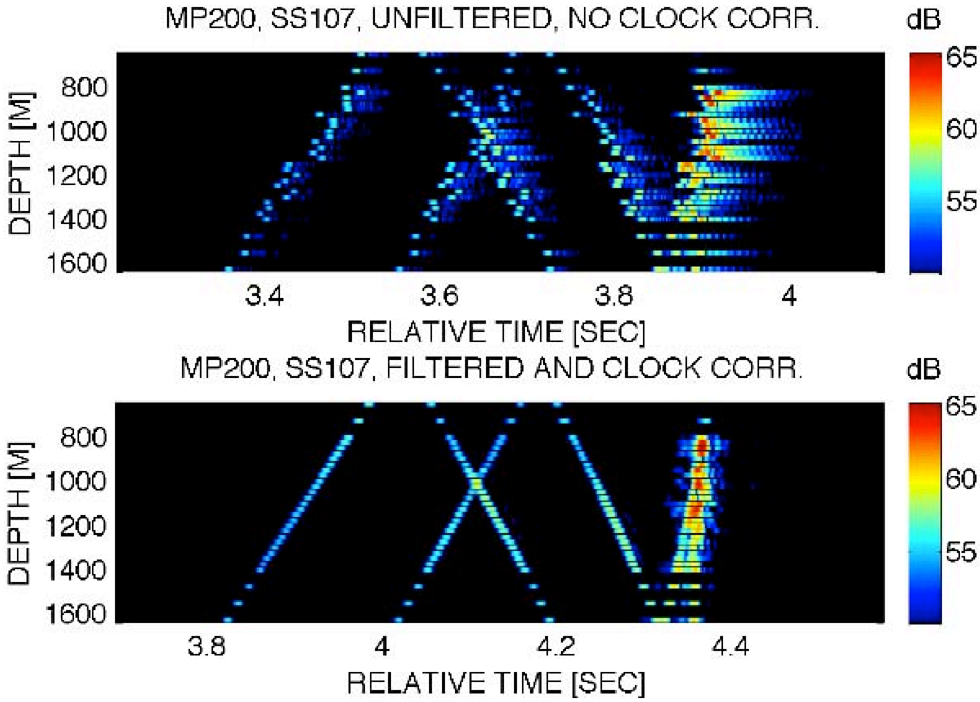



***Figure 16. An example timefront from SS107 before and after clock corrections and filter are applied to data.***

**IMPACT/APPLICATIONS**

This research has the potential to affect the design of long-range acoustic systems, whether for acoustic surveillance, communication, or remote sensing of the ocean interior. The data from the NPAL network, and the special NPAL experiments, indicate that existing systems do not exploit the limits of acoustic coherence at long ranges in the ocean.

Estimates of basin-wide sound speed (temperature) fields obtained by the combination of acoustic, altimetry, and other data types with ocean general circulation models have the potential to improve our ability to make the acoustic predictions needed for matched field and other sophisticated signal processing techniques and to improve our understanding of ocean variability.

**RELATED PROJECTS AND COLLABORATIONS**

A large number of additional investigators have been involved in ONR-supported research related to the NPAL project and participate in the NPAL Workshops, including Art Baggeroer (MIT), J. Beron-Vera (UMiami), M. Brown (UMiami), J. Colosi (NPS), N. Grigorieva (St. Petersburg State Marine Technical University), F. Henyey (APL-UW), V. Ostashev (NOAA/ETL), R. Stephen (WHOI), A. Voronovich (NOAA/ETL), K. Wage (George Mason Univ.), Peter Worcester (Scripps), and others. In addition, we have begun close collaboration with Gerald D'Spain who is funded by the signal processing code of ONR.

In addition to supporting the APL-UW cruise in PhilSea10, Rex Andrew participated in the SIO cruise led by Peter Worcester.

Immediately after the SIO cruise, APL-UW transmitted the CTD casts made during the cruise to Terry Rago of NPS, who graciously processed and re-formatted the data into R-T messages, which he then sent on to NAVOCEANO.

We supplied Dr. Tarun Chandrayadula (currently a National Research Council Post-Doctoral Fellow working with Prof. J. A. Colosi at the Naval Postgraduate School) with both transmission diagnostic files from the APL/UW transmitter and acoustic hydrophone receiver files from the Scripps deep and shallow vertical line arrays from multiple stations in the 2004 LOAPEX experiment.

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